A REVIEW OF THE DIFFERENCE AMONG MACROSCOPIC, MICROSCOPIC AND MESOSCOPIC TRAFFIC MODELS

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ABSTRACT

The fundamental traffic flow description on roadways were obtained from research by Greenshields in 1934, for the first time, he performed tests to measure the flow of traffic, the density of traffic and speed using a photographic approach.

Greenshields developed a mathematical model which gave a linear relationship between the flow, speed and density of vehicles on the roadways.

Over the years, different traffic flow description models have evolved to give an in-depth detail of the interaction between vehicles and the roadway, such models include the microscopic, macroscopic and mesoscopic models.

Microscopic models describe and analyse the behaviour of individual vehicles in a traffic stream, Macroscopic models give a general description of vehicles and traffic as a continuum, Mesoscopic models which are more recent, serve as an intersection between the Micro- and the Macro- levels of vehicular and traffic description.

This paper gives a review of what these models encompass individually, the similarities, the differences, and the application of each model in real life cases.

Keywords: Traffic models, Microscopic, Macroscopic, Mesoscopic

Chapter 1 Introduction

There have been numerous models describing traffic flow on highways since the development of the first model, these have risen as a result of different criticism over the previous models and observed lags in preceding models, thereby making different researchers test to improve the accuracy of other models.

It is important to know the source of these models, the limitation of each model as they evolved, the improvement made by new models, the differences in method of description and the area of application of these models.

A detailed description of the origin of the microscopic, macroscopic and the mesoscopic models, the lags, the difference, similarities, and the application will be given in this paper.

Macroscopic stream models present how the change in the behaviour of one parameter of traffic flow affects the other, they classify the operational characteristics as being an aggregate, instead of being considered separately as to microscopic models. The major parameters that are used in modelling the traffic flow on freeways in macroscopic level includes the speed, density and flow.

Modelling of traffic flow at the macroscopic level originated under the assumption that traffic streams as a whole can be compared to fluid streams.

All traffic models were born from criticism of tests carried out by Greenshields in 1934, which gave birth to a linear relationship between the flow, speed and density of vehicles in the traffic stream on a highway. Researchers such as Greenberg, North-western, Underwood, Edie, Lighthill and Whitham, all have been improving upon the research ignited by Greenshields through constructive criticism to improve effectiveness of each model as they are proposed.

Microscopic models consider individual vehicle parameters in the operation of traffic on highways. A car-to-car characteristics is considered in modelling the operation of individual vehicles, parameters such as time headways, distance headways are used in these models.

Microscopic models can be classified majorly into two, namely, the general car following models and the safe-distance models. The general car following models assumes that the following characteristic of a driver depends on his response to stimuli induced by the leading driver, the safe-distance model are based on the assumption that the following driver seeks to maintain a safe distance between him and the following driver to avoid collision. Examples of each models types are the General motors theories and the Pipes theory respectively.

Mesoscopic models serve as a bridge between models at macro- and the micro- levels. These models are referred to as the hybrid models, and are still limited to tests in the research work alone. These model seems to take a differential approach in calibrating the traffic flow parameters. Researchers such as Lighthill, Whitham, Richards, Hoogendorn, Hunfield, and Paveri Montana are frontiers in finding a more effective measure of calibrating the traffic stream characteristics using these hybrid models.

Chapter 2 Literature review

Ramachandran et al demonstrated the use and benefits of (Origin-Destination) O-D flow approach in calibrating microscopic traffic condition on a freeway and parkway network where heavy traffic conditions are experienced during commute periods, the truck traffic was treated independently using multi class models. Using count data from 33 sensors, and 482 O-D pairs, flows between the O-D pairs were estimated for each 15-min departure time interval, SPSA algorithm was used because of its large scale data computation effectiveness. Results show that the O-D approach of modelling microscopic characteristics gave accurate results and also has an advantage of modelling the parkway access restrictions for heavy vehicles using a multi class approach and also simultaneously estimates all microscopic simulation model parameters by using general traffic measurements.

Tampere et al proposed a modelling technique that bridges the gap between microscopic behaviour of individual driver and macroscopic dynamics of flow. Using gas kinetic models, a macroscopic traffic flow model was derived analytically from individual driver specification, which treats response variable as continuous adaptive process. This model can be used to account for flows that cannot be observed such as vehicles equipped with ADA systems. Also a simple car following model with overtaking opportunities was implemented which is also potentially applicable to more complex driver behaviour specifications to produce strong results.

Hoogendoorn and Bovy, after discovering that the traditional gas kinetic model failed to correctively interpret the flow regime interaction, studied the interaction of constrained and uncongested vehicles using multi lane multi class (MLMC) approach, this model is referred to as the improved gas kinetic model and describe multi lane heterogeneous traffic flow. Using a method similar to method of moments, the model is able to successfully calibrate continuum traffic flow variables, such as spatial density, traffic impulse and kinetic traffic energy for different lane users.

Chapter 3 Methodology

In this chapter, the characteristics of each model level are presented in a sequential order, which is from macroscopic to microscopic and to mesoscopic. A brief introduction of the work done by major researchers is each aspect is explained, their assumptions, approach and initial results from their research is provided and a real life data is used in calibrating some of these models. Regression analysis is used in calibrating each of the macroscopic traffic models presented in this paper, and the results are presented as obtained.

3.1 Macroscopic Traffic Models

3.1.1 Single Regime Models

Greenshields in 1934 collected data using photographic approach, by mounting a video camera with motor attachment adjacent a highway which took pictures of moving vehicles on the highway, making moving cars appear in at least two consecutive pictures. A laboratory procedure was used to estimate the time interval between the vehicles, the rate of flow per distance and the speed at which they moved. *(Transportation research circular June 2011)*

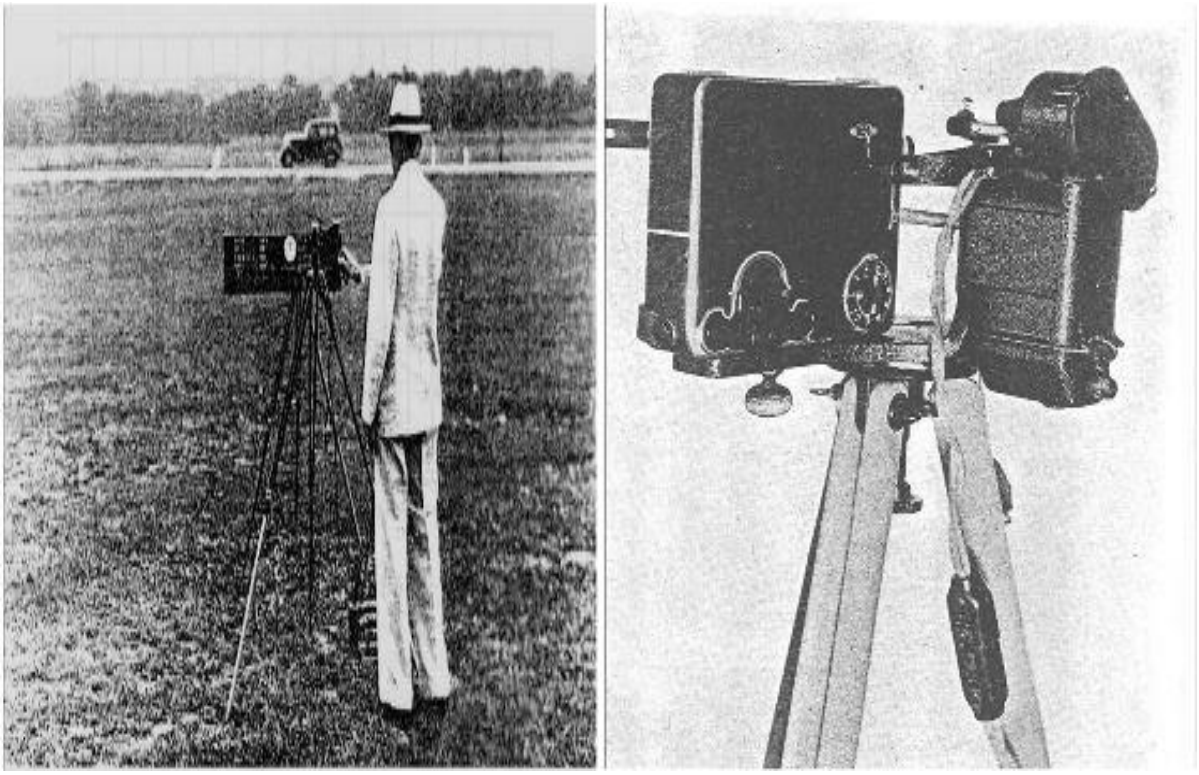


Fig. 1 (a) Greenshields taking measurements, (b) set-up of the camera and motor attachment. (Adapted from transportation research circular June 2011)

From the tests, the linear relationship developed is given as:

$$Us = Uf - \frac{Uf}{Kj}K$$

Where U_s = average speed

U_f = free flow speed of vehicles

k_j = jam density of vehicles

K = density

This linear relationship gave birth to the fundamental diagrams of traffic flow which all other evolving models were based upon.

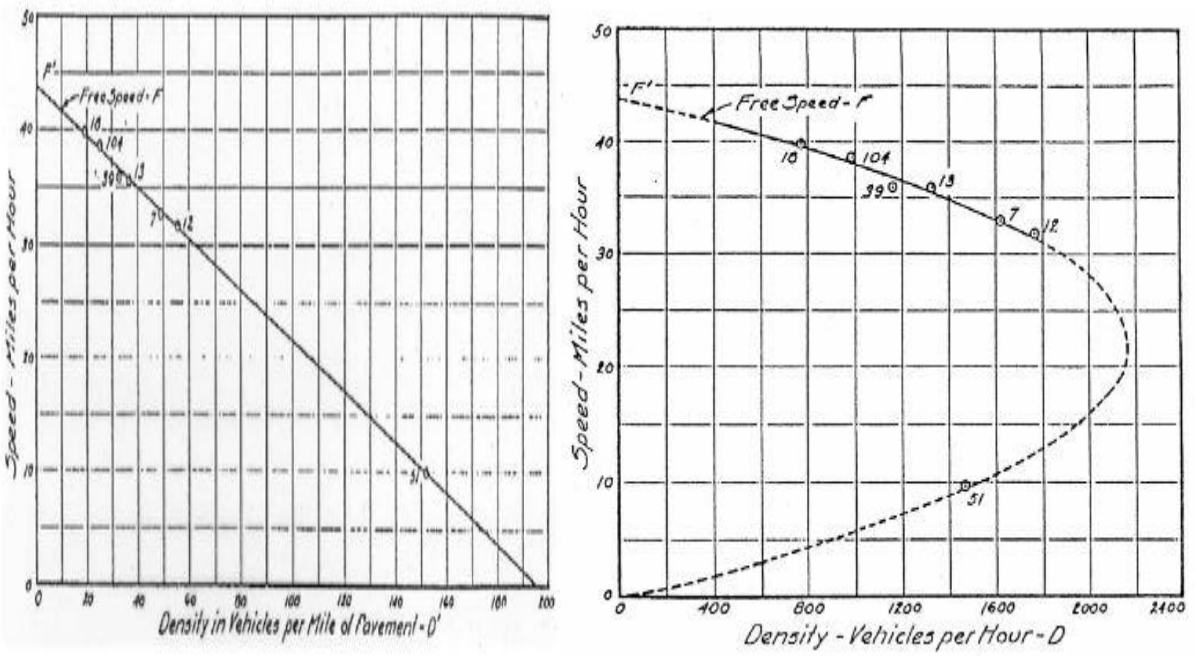

Free Speed - F
Speed - Miles per Hour
Density in Vehicles per Mile of Pavement - D
Free Speed - F
Speed - Miles per Hour
Density - Vehicles per Hour - D

Fig 2(a) speed-density (Greenshields) *(b) speed-flow (Greenshields)*

This fundamental diagram brought about the development of other graphical representation of these relationship. Daganzo (1994) proposed a bi-linear relation in the density-flow plane, Smulders (1990) gave a parabolic-linear representation, parabolic for low flow densities and linear for high flow densities, Drake (1967) also proposed different graphical relationships between flow, speed and densities. *(Femke et al 2014)*

The limitations discovered in the Greenshields model was that it requires the jam density which is difficult to obtain, also, the optimum density K_o which is the average of the jam density in real life is not realistic.

Other limitations observed are:

- The data was based on a non-freeway road, where lane changing is accepted, i.e., it was on a two-lane, two-way road. Traffic flow models these days are usually based on a freeway operation.
- In Greenshields calibration, tit can be observed that most of the data obtained were on the free flow region, and just one data point was on the congested flow region, which gives a biased relationship.
- There was also 90% overlapping in data collection.
- The Greenshields data was based on holiday data, which is already experiencing a temporal variation of flow.

These limitations gave rise to other single regime models and also multiple regime models.

Following the limitations in Greenshields single regime model, the Greenberg model (1959) arose as the second single regime model, with more attention to the congested region on the speed-flow diagram. He considered a non-linear model as more appropriate in defining the relationship between the speed and density.

Using the analogy of one-dimensional fluid flow theory and equations of motion, he successfully compared the operations on a freeway and he arrived at the relationship:

$$U_s = U_o \ln kj/k$$

The Greenberg model also required the knowledge of the optimum speed and jam density, which are difficult to measure, the free flow speed is also assumed to be infinity.

Other single regime macroscopic models came as sub-models of the major models described above, and a brief overview is given below.

Underwood (1961) studied the free-flow region of the Greenshields model and was also concerned with the free flow speed of Greenberg model being infinity, so he developed a new model

$$U_s = U_f \ e^{\frac{k}{ko}}$$

This requires the knowledge of free flow speed and optimum density which is difficult to obtain, and it also assumes that the jam density is infinite.

Drew (1968) formulated a model based on the Greenshields model, but introduced a parameter 'n'

$$U_s = U_f \left[1 - \left(\frac{k}{kj}\right) n + 1\right]$$

For different values of n, a different model is arrived at, when n= 1, the linear relationship is obtained, when n = 0, there is a parabolic relationship, and when n = -1, there is a negative exponential relationship.

3.1.2 Two regime models

Edie (1961) proposed a two-regime model, which combines the operations in both the free-flow region and the congested flow region, he proposed that the free flow region of the traffic flow can be characterized to follow the underwood exponential model, while the congested flow region can be characterized as following the Greenberg model. The challenge associated with this model is the determination of the break point between the free flow region and the congested flow region. *(Adolf D. 1990)*

3.1.3 Multi Regime Models

Three regime model also evolved, which separates the free flow regime, the congested flow regime and the extreme region of the flow from each other.

Different relationships were formulated to characterize the macroscopic relationship of traffic elements at this different regions of flow in order to give more accurate results.

Using these models, and a real-life data obtained from them north-bound approach of a highway, the different models are calibrated using regression analysis results from the combination of EXCEL and MATLAB software. The parameters obtained and the resulting equations are summarised in the following table, and the relationship between the macroscopic characteristics follows the table.

Table 1(a) calibration results obtained from single regime models using regression analysis

Model	**Equation**	**Calibration**	U_f***(mph)***	K_j**(pcpmpln)**
Greenshields	$U_s = U_f(1 - K/K_j)$	74.29-0.53k	74.29	139.6
Greenberg	$U_s = U_o ln(K_j/K)$	79.82-5.76*ln*k	inf	1.1E6
Underwood	$U_s = U_f e^{\frac{k}{ko}}$	$76.73e^{-0.001k}$	76.73	101
North-western	$U_s = U_f e^{-1/2\left(\frac{k}{ko}\right)2}$	$71.55e^{-0.0002k^2}$	71.55	

Table 1(b) calibration results obtained from multi regime models using regression analysis

Model	**Calibration**	U_o**(mph)**	U_f**(mph)**	K_j**(pcpmpln)**
Edie	$74.41e^{-0.008k}$, k<51 233.99-50.84*ln*k, k>50	233.99	74.41	98.778
Three regime model	71.71-0.3486k, k<41 94.16-1.16k, k =41:65 44.5-0.3496k, k >65		71.71 94.16 44.5	205.71 81.17 127.29

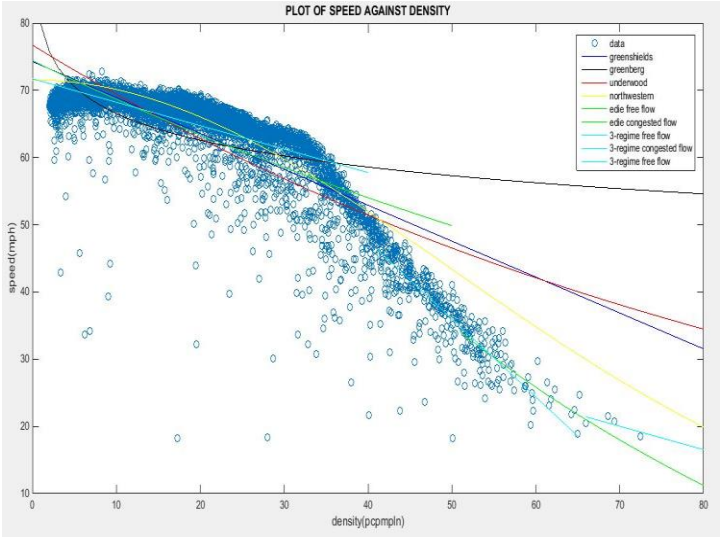


Fig.3 (a) plot of speed against density using single regime and multi regime models

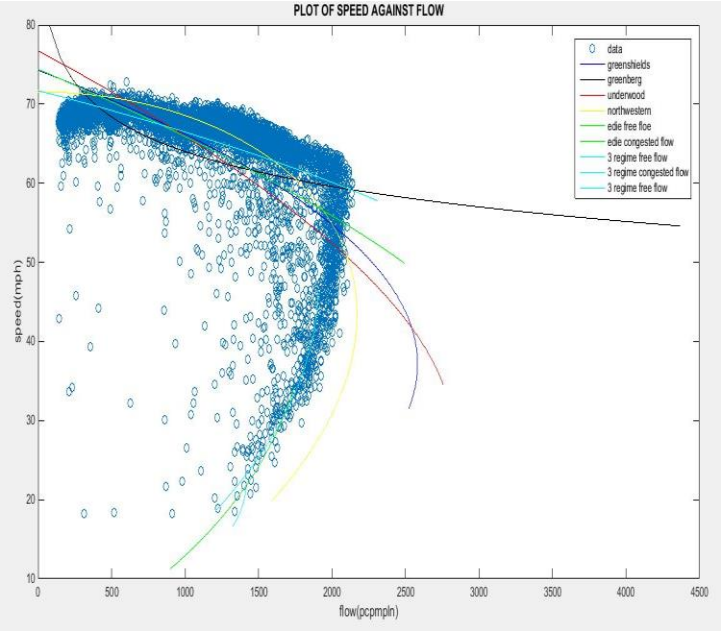


Fig.3 (b) plot of speed against flow using single regime and multi regime models

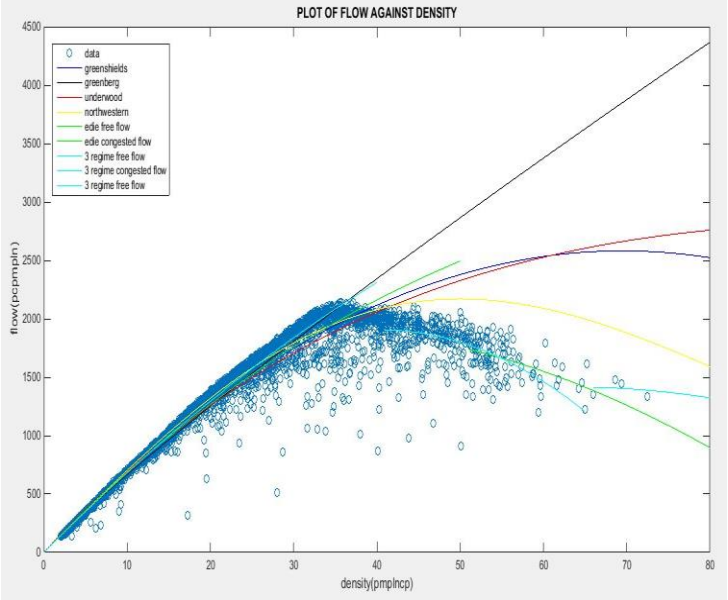


Fig.3 (c) plot of flow against density using single regime and multi regime models

3.2 Microscopic Traffic Models

Microscopic traffic models define the operation of a traffic system based on individual vehicle characteristics. They are detailed models that are at a fine scale and typically include all streets and components of the transportation system that impact travel. Such elements can include intersection control and striping, pedestrian crossings, transit stops, and even the inclusion of traffic calming measures.

Microscopic traffic models are calibrated using disaggregate data. They are regarded as non-continuum models, which require input of parameters such as lane changing, free flowing, car following and route choices in calibrating. Early research were mainly based on two major models, the general car following and the safe distance models.

Pipes (1953) and Reuschel (1950) developed the relationship between pair of cars following each other. Pipes suggested that a good rule for following another vehicle at a safe distance is to allow yourself at least the length of a car between your vehicle and the vehicle ahead for every ten miles per hour of speed at which you are travelling. *(Adolf D. 1990)*

Pipes model gave a relation between distance headway and the speed of the following vehicle as:

$$d_{min} = L_n[x_{n+1}/(1.47*10)] + L_n$$

Pipes concluded that the minimum safe distance headway increases linearly with speed and theoretically reaches an absolute minimum time headway of 1.36 seconds at a speed of infinity. (Adolf M).

Forbes(1958) in his research considered the minimum safe distance required for two vehicles following each other in a traffic stream, and proposed that the minimum distance required must be equal to or greater than the perception reaction time of the following driver.

Forbes model resulted in the relationship between the time headway and the velocity of the leading vehicles as:

$$h_{min} = \Delta t + L_n/x_n$$

Forbes also concluded that the minimum safe distance headway increases with speed, while the minimum safe time headway decreases with speed.

General motors researchers in their work continuously derived relationships between the response of a driver, the sensitivity, and the stimulus involved in the car following behaviour. The stimulus was the relative velocity, while the response was the acceleration. The major difference between these relationship developed was the sensitivity factor. They came up with five different models which are tabulated below.

Table 2. General motors models

Model	Equation
GM first model	$\ddot{x_{n+1}}(t+dt) = \propto [\dot{x_n}(t) - \dot{x_{n+1}}(t)]$
GM second model	$\ddot{x_{n+1}}(t+dt) = \propto_1 or \propto_2 [\dot{x_n}(t) - \dot{x_{n+1}}(t)]$
GM third model	$\ddot{x_{n+1}}(t+dt) = \frac{\propto_0}{x_n(t) - x_{n+1}(t)} [\dot{x_n}(t) - \dot{x_{n+1}}(t)]$
GM fourth model	$\ddot{x_{n+1}}(t+dt) = \frac{\propto' [\dot{x_{n+1}}(t+dt)]}{x_n(t) - x_{n+1}(t)} [\dot{x_n}(t) - \dot{x_{n+1}}(t)]$

GM fifth model	$\ddot{x_{n+1}}(t+dt) = \frac{\propto_{l,m} [\dot{x_{n+1}}(t+dt)]^m}{[x_n(t) - x_{n+1}(t)]^l} [\dot{x_n}(t) - \dot{x_{n+1}}(t)]$

Microscopic models are usually difficult to calibrate owing to the large number of parameters needed to be obtained in order to get result, not only do these data need to be obtained but also need to be accurate in order to get realistic results. This complexity led to the formulation of a different approach regarded as the Origin-Destination (O-D) approach.

The O-D flow approach of microscopic modelling depends on count data related to travel times of vehicles. The O-D flow may be estimated, while the driver behaviour parameters are fixed, alternatively, parameters such as the lane changing, car following and free flowing parameter may be estimated while the O-D flow is fixed at their best known values. *(Ramachandr et al., "calibration of microscopic simulation models; methods and application).*

The time-dependent O-D matrix defines the number of trips between each O-D pair departing the respective origin during time interval.

3.2 Mesoscopic Traffic Models

Mesoscopic analysis of traffic is the hybrid between the macroscopic analysis and the mesoscopic analysis level of modelling. They describe the vehicle behaviour in aggregate terms such as probability distributions, also, behaviour rules are defined for individual vehicles. The family include gas-kinetic and cluster models. The most popular being the gas kinetic models. *(Femke et al 2014).*

Gas kinetic models originally used in contemporary physics were used to describe the motion of large number of small moving particles in a gas, when applied to the motion of vehicles in a traffic stream can be used to describe the variation of velocity distribution functions of vehicles. *(Femke et al 2014).*

Prigogine and Andrews (1960) introduced gas kinetic models using calculus approach as:

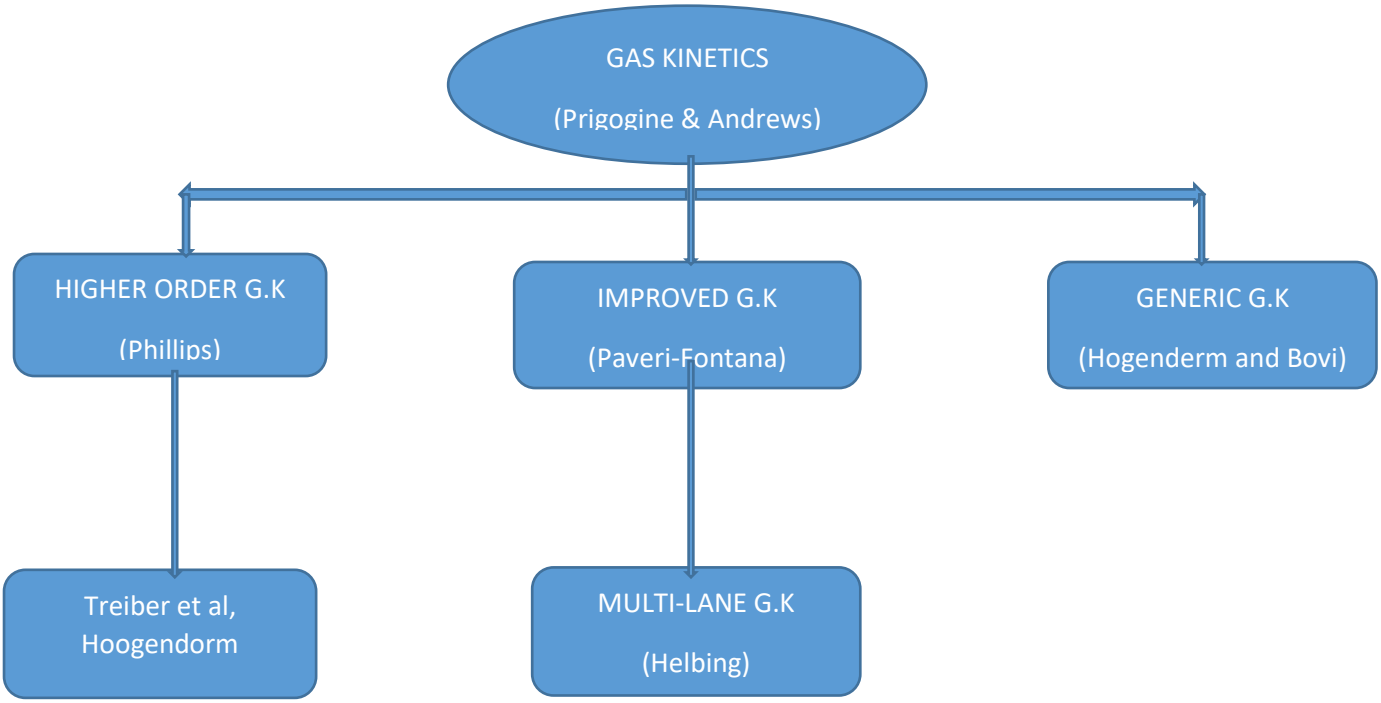
$$\frac{\partial p}{\partial t} + v\frac{\partial p}{\partial x} = \left(\frac{\partial p}{\partial p}\right) acc + \left(\frac{\partial p}{\partial t}\right) int$$

Where p is the reduced phase-density. This is based on the assumption that the behaviour of nearby vehicles do not correlate to each other.

Paveri (1975) improved upon the gas kinetic model by relaxing the assumption that the behaviour of nearby vehicles in the traffic stream is not correlated, which resulted in the interaction term adapted in the original gas kinetic model.

Helbing (1999) innovated the multi-lane traffic models which treats each lane differently and additional terms are introduced into the kinetic equation, such as the velocity diffusion term, lane changing term, rate of vehicle entrance and leaving. However these models are only used in research and are yet to be incorporated into practically applicable models.

A schematic representation of evolution of these models is given below.



The LWR mesoscopic model proposed that the motion of vehicles follows a conservative equation given as:

$$\frac{\partial p(x,t)}{\partial t} + \frac{\partial q(x,t)}{\partial x} = 0$$

Where p(x,t) is density and q(x,t) is the traffic flow, with a statistical relationship between flow and density, q = Q(p), which is known as the fundamental diagram. The LWR model is quite easy to interface with microscopic models. The vehicle characteristics in this model are considered homogenous, which therefore imposes a limitation when the LWR model is combined with the microscopic model that account for heterogeneous traffic characteristics such as different vehicle classes, thereby resulting in a loss in information regarding vehicle and driver characteristics between the interface of the microscopic model and LWR model due to integration of the vehicle trajectories to a continuum.(*Joueiai et al, "Multiscale traffic model based on the mesoscopic lighthill-whitham and Richards models*)

Finally, it can be seen from the paper that the overall difference between continuum and non-continuum models is dependent on the scale of calibration of these models. However, an in-depth consideration reveals that more specific difference comes from the different assumptions made in developing each of the sub models under these two major models. Another difference lies in the parameter and data required in calibrating each of these models.

Chapter 4 Conclusion and Recommendation

This paper presents a review of the existing major macroscopic, microscopic and mesoscopic traffic models. It looks into the work of each major researcher, their assumptions, their conclusion, the models developed and the recommendations they provided. The models are calibrated based on real life data, and results are obtained as expected.

In case of the macroscopic models, the speed, flow, and jam density are used in determining the effectiveness of each model and are compared to each other. From results obtained in calibration, it can be observed that all single regime models seem to have their free flow speed close to each other, with the underwood model having the highest free flow speed and the lowest jam density, it is also seen that the Greenshields has a lower free flow compared to underwood but has a higher jam density, which would confirm an inverse relationship between the two regimes. Multi regime models are also a follow up of the single regime models but regarding the three regime flow model, a lower free flow speed is obtained but a higher jam density is also obtained for the congested flow region, the free flow region has a very high speed and a lower jam density compared to the congested flow region, while the region with lowest traffic has the lowest speed, which would reflect that this model fits the data perfectly. Continuum models are very easy to calibrate and require less data, however, it is recommended that these models should be developed to better track vehicle characteristic such as travel type, vehicle type, contraflow traffic and other driver characteristics. However, it is recommended that future research should be done in order to make these model more detailed to give more vehicle characteristics and still remain simple to calibrate.

Microscopic models are the most effective model in terms of the parameters of estimation, such as the response to stimuli and the safe distance maintained to avoid collision and the minimum perception reaction time. These models give detailed and accurate results when calibrated. However, the difficulty in calibration due to requirement of large number of variables is of major concern. It is recommended that more research work should be done on these models to probably decrease the number of variable needed to calibrate them.

Mesoscopic models in the field of transportation are still lagging in practical application as the findings are still limited to the laboratory tests. These models however tend to give a faster and easier approach to modelling continuum and non-continuum models as the interface of these model provide the user with microscopic characteristic of the data obtained. From literatures reviewed, mesoscopic models also tend to look quite complicated in modelling, just like microscopic models, probably due to the differential approach used and the gas momentum assumption made, and this may pose a challenge in applying them to real life situation. It is recommended that further research should be done to synchronize the homogenous assumption of mesoscopic models with the heterogeneous assumption of microscopic models.

Appendix: Calibration of Macroscopic Models on MATLAB

Command Window

```
>> plot(density,speed,'o')
>> hold
Current plot held
>> xp = [0:80];
>> densigs = 74.28587 - 0.534412*xp;
>> densigb = 79.817795 - 5.755656*log(xp);
>> densiun = 76.73325*exp(-0.01*(xp));
>> densinw = 71.54767*exp(-0.0002*(xp.^2));
>> xy = [0:50];
>> densiedun = 74.41*exp(-0.008*(xy));
>> xs = [51:80];
>> densiedgb = 233.99 - 50.84*log(xs);
>> xz = [0:40];
>> densitrlo = 71.71 - 0.3486*xp;
>> xza = [ 41:65];
>> densitrlt = 94.162 - 1.163*xza;
>> densitrlo = 71.71 - 0.3486*xz;
>> xzb = [66:80];
>> densitrlth = 44.5 - 0.3496*xzb;
>> plot(xp,densigs,'b')
>> plot(xp,densigb,'k')
>> plot(xp,densiun,'r')
>> plot(xp,densinw,'y')
>> plot(xy,densiedun,'g')
>> plot(xs,densiedgb,'g')
>> plot(xz,densitrlo,'c')
>> plot(xza,densitrlt,'c')
>> plot(xzb,densitrlth,'c')
>> plot(flow,speed,'o')
>> qgs = densigs.*xp;
>> qgb = densigb.*xp;
>> qgun = densiun.*xp;
>> qgnw = densinw.*xp;
```

Command Window

```
>> qedun = densiedun.*xy;
>> qedgb = densiedgb.*xs;
>> qtrlo = densitrlo.*xz;
>> qtrlt = densitrlt.*xza;
>> qtrlth = densitrlth.*xzb;
>> hold
Current plot held
>> plot(qgs,densigs,'b')
>> plot(qgb,densigb,'k')
>> plot(qgun,densiun,'r')
>> plot(qgnw,densinw,'y')
>> plot(qedun,densinw,'g')
```

```
>> plot(qedun,densiedun,'g')
>> plot(qedgb,densiedgb,'g')
>> plot(qtrlo,densitrlo,'c')
>> plot(qtrlt,densitrlt,'c')
>> plot(qtrlth,densitrlth,'c')
>> % plot of flow against density
>> %--------------------------------
>> plot(flow,density)
>> plot(density,flow,'o')
>> plot(xp,qgs,'b')
>> plot(density,flow,'o')
>> hold
Current plot held
>> plot(xp,qgs,'b')
>> plot(xp,qgb,'k')
>> plot(xp,qgun,'r')
>> plot(xp,qgnw,'y')
>> plot(xy,qedun,'g')
>> plot(xs,qedgb,'g')
>> plot(xz,qtrlo,'c')
>> plot(xza,qtrlt,'c')
>> plot(xzb,qtrlth,'c')
```

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